

## **Distribution, Abundance and Population Structuring of Beaked Whales in the Great Bahama Canyon, Northern Bahamas**

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Award Number: N000140710120  
Award Number: N0001409IP20051  
<http://www.bahamaswhales.org>

### **LONG-TERM GOALS**

Atypical mass strandings of beaked whales have been correlated with naval sonar exercises (e.g. Simmonds and Lopez-Juraco 1991; Frantzis 1998; Evans and England 2001) highlighting a need for a better understanding of beaked whale population ecology. The long-term goal of this project is to fill key data gaps on the distribution, abundance, habitat use and population structuring of beaked whales in the Great Bahama Canyon. The study area includes the US Navy's Andros-AUTEC Operating Areas where fleet readiness training involves regular use of mid-frequency active sonars, providing opportunity to compare aspects of the population ecology of beaked whales found on and off the Navy range.

### **OBJECTIVES**

The primary objectives of the study are:

- 1) To use visual survey techniques to document beaked whale distribution and habitat use, and to estimate abundance in the Great Bahama Canyon.

Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE <b>30 SEP 2011</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-2011 to 00-00-2011</b>	
4. TITLE AND SUBTITLE <b>Distribution, Abundance and Population Structuring of Beaked Whales in the Great Bahama Canyon, Northern Bahamas</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Bahamas Marine Mammal Research Organisation,P.O. Box AB-20714,Marsh Harbour,Abaco, Bahamas,</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES <b>8</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

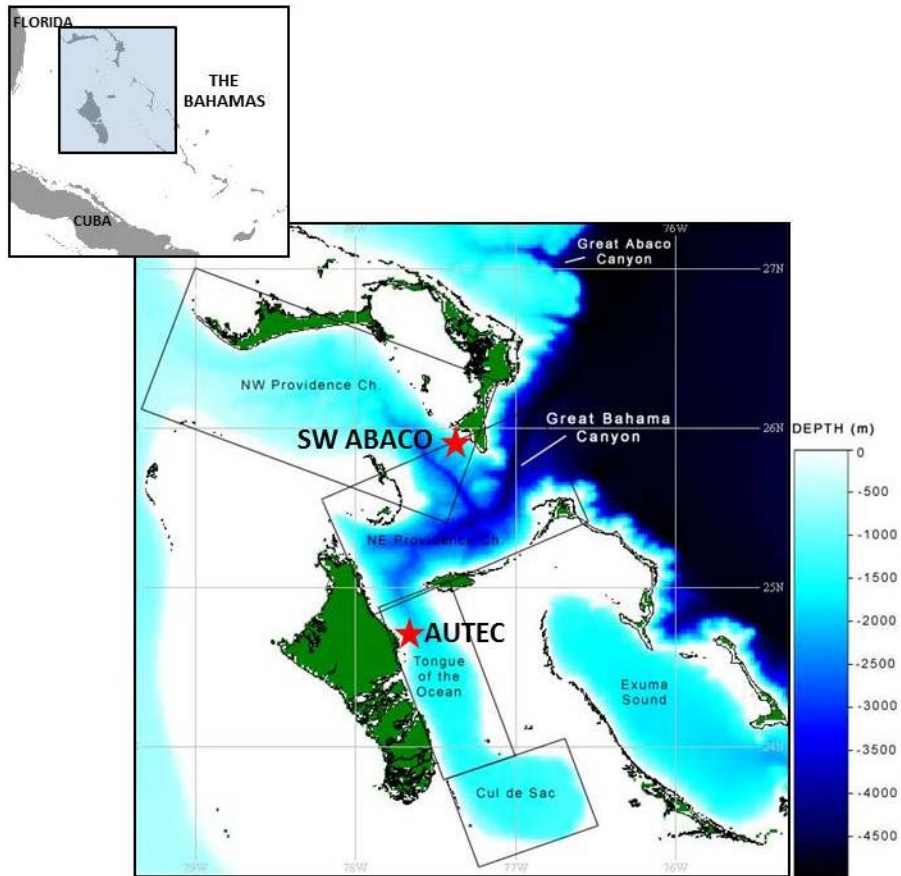
- 2) To use photo-identification techniques to extend an existing photographic catalogue of individual beaked whales, to examine the distribution and movements of identified individuals and assess abundance using mark-recapture techniques.
- 3) To use remote biopsy techniques to collect skin and blubber samples to contribute to the study of beaked whale diet (through fatty acid, stable isotope and contaminant analyses) and stock structure (using molecular genetic approaches).

## APPROACH

Using standardized line-transect methods, three ship-based visual and acoustic surveys were completed during FY07-08 to assess patterns of distribution and relative abundance of beaked whales in the Great Bahama Canyon. Transect lines were randomly placed within four rectangular strata (NE Providence Channel, NW Providence Channel, Tongue of the Ocean and the Cul de Sac, Figure 1). When beaked whales were sighted, the ship broke transect to confirm species identification, estimate group size and to collect photo-ID and biopsy samples. An additional fourth survey in FY09 returned to areas of highest concentration of beaked whales to increase the number of biopsy samples and to deploy satellite dart-tags. Additionally, small vessel surveys were conducted outside the Great Bahama Canyon during FY10 (in Exuma Sound and the Great Abaco Canyon) to evaluate population structuring and movement patterns of beaked whales. Small vessel surveys were conducted in FY11 off the southwest coast of Great Abaco Island, where longitudinal photo-identification data exist, to contribute to mark-recapture analysis and collect biopsy samples for contribution to the population genetics study as well as other ONR-funded work.

The photo-identification data are being used to compare abundance and turnover (emigration from and re-immigration into the study area) of Blainville's beaked whales (*Mesoplodon densirostris*) in two areas of equal size (~500 km<sup>2</sup>) on and outside the Atlantic Undersea Test and Evaluation Center (AUTC). Using methodologies developed by Durban and Elston (2005) and Matkin *et al.* (in press), mark-recapture models are being fit to photo-identification data collected between March to October during 6 years (2005-2010) at AUTC, where mid-frequency active sonars are used regularly; and off the SW coast of Abaco Island (~170 km away, Figure 1), considered a control study site where navy sonar is not used regularly. Open-population mark-recapture models are being fit to the photographic data to estimate abundance and turnover in these areas using a parametric Bayesian approach.

Tissue samples collected during this study are being used for population genetic structure analyses of beaked whales (*Ziphius cavirostris* and *Mesoplodon densirostris*). The samples consist of skin biopsies, sloughed skin, feces, and bone collected around the northern Bahamas. A portion of the mitochondrial control region that has previously been used for phylogenetic studies of beaked whales is being sequenced, and sexing of all samples is being done using a real-time PCR based method. In addition, approximately 50 single nucleotide polymorphism (SNP) markers are being developed at which to genotype all samples. The data will be used to investigate gene flow and population substructuring around the sampled regions. Estimates of relatedness and phylogeography will be used to evaluate site fidelity and social structure.

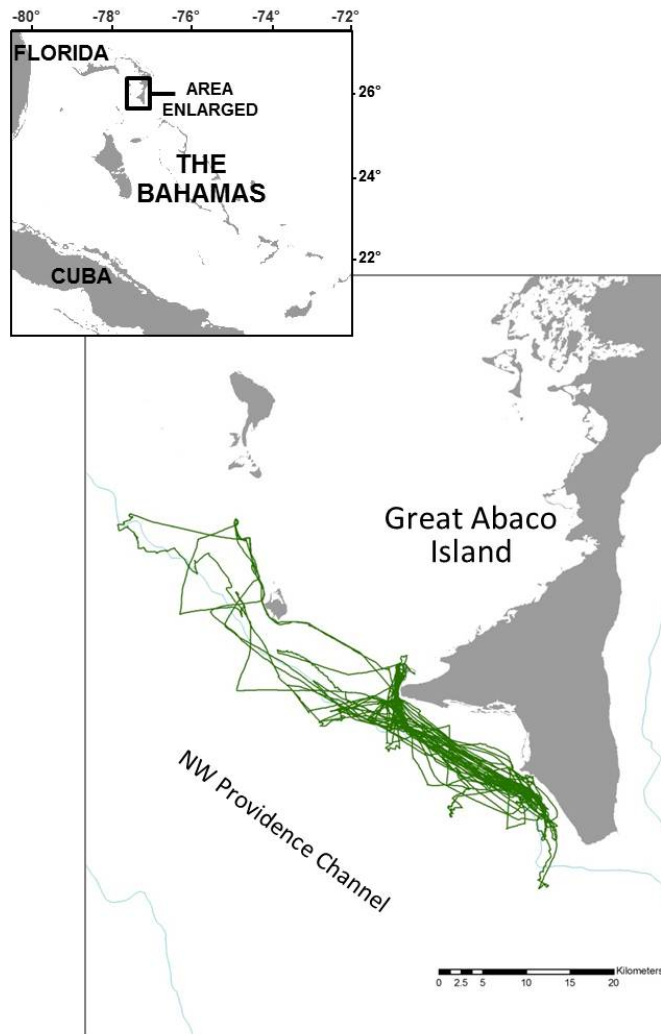


**Figure 1.** *The Great Bahama Canyon branches northwards into Northwest Providence Channel and southwards through Northeast Providence Channel into Tongue of the Ocean and the Cul de Sac, and reaches depths of more than 4000m. Ship-based surveys have been conducted within rectangular grids in these 4 parts of the canyon. Biopsy sampling has also taken place outside the canyon, in Exuma Sound, to the SE and in the Great Abaco Canyon, to the NE. Small-vessel surveys were conducted during FY11 in the SW Abaco long-term study site. The location of the US Navy's AUTEC facility in Tongue of the Ocean is also shown.*

## **WORK COMPLETED**

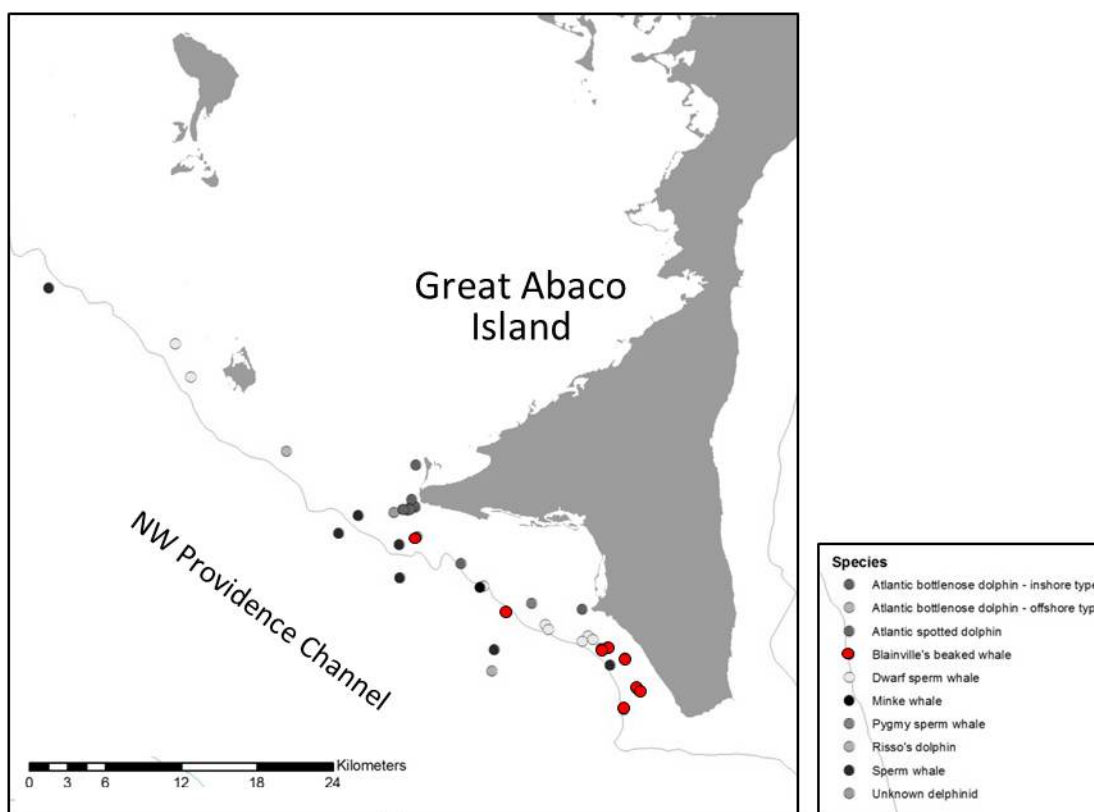
### Data Collection

During FY11 vessel-based surveys were conducted off the southwest coast of Great Abaco Island to search for beaked whales (Figure 2). Using a 6.8m rigid-hulled inflatable, visual search effort took place during twenty-three surveys covering 1795 km.



**Figure 2. A 6.8 m RHIB conducted vessel surveys off the southwest coast of Great Abaco Island in Northwest Providence Channel, northern Bahamas. The vessel tracks are shown here as green lines, and were primarily focused along the lee shore of the island. The 1000 m isobath is also shown (blue line).**

There were 48 cetacean sightings, including 8 different species (Figure 3). There were 8 sightings of Blainville's beaked whale (*Mesoplodon densirostris*), during which 5 biopsy samples were collected. Additional biopsy samples were collected from sperm whales (n=2) and bottlenose dolphin (oceanic ecotype, n=3). The samples from beaked whales and sperm whales were split into skin and blubber portions; the beaked whale skin portion is being used for genetics (Morin, this study), the sperm whale skin portion will contribute to a population structuring study (Kim Parsons (NWFSC), SERDP-funded project for which Claridge is Lead PI) and the blubber from both species is to be used in a study of reproductive rates and stress (Nick Kellar (SWFSC), ONR-funded N0001411P20080). Additionally, thirteen groups of *M. densirostris* were sighted and photo-identified during field work carried out in SW Abaco during July 2011 which was providing leverage to the ONR-funded study using fecal steroid hormone assays to assess stress responses (see Rolland and Claridge FY11 report).



**Figure 3. Cetacean sightings during FY11 off the southwest coast of Great Abaco Island in Northwest Providence Channel, northern Bahamas. Eight different species were found, including Blainville's beaked whale (n=8, shown in red).**

#### Mark-recapture Analyses

Photographs were graded for quality and individuals were rated on presence or absence of notches in the dorsal fin and graded for distinctiveness. At the AUTECH site, there were 36 distinctively-marked whales identified from high-quality photographs, with 11 whales seen in multiple years (median 2, maximum 4 years). At SW Abaco, there were 46 individual identifications with 16 whales seen in more than one year (median 3, maximum 5 years). Identification histories were compiled for each individual whale, consisting of a binary history over a series of annual sampling intervals which extended from March through October within the study period (2005-2010).

#### Genetic Analyses

In 2010 the Southwest Fisheries Science Center's Marine Mammal Genetics Group completed sequencing of 24 sequences for SNP discovery, but relatively few usable SNPs were found, which enabled the team to design only 7 SNP genotyping assays. New sequencing technologies presented an opportunity to sequence an additional ~60 loci in a single sequencing experiment, expanding the original sequence list and simultaneously providing whole mitochondrial genomes from 23 individuals of each species (plus 9 *M. europaeus*). This additional sequencing was completed in July 2011, and the data for SNP discovery are currently being analyzed. Analysis of mitogenome data will now begin to look at within- and between-ocean basin variability in *M. densirostris* and *Z. cavirostris*. SNP

discovery and assay design is expected to be completed by the end of Nov. 2011 and genotyping by early 2012.

Additionally, DNA was extracted from all samples received through June 2011. A genetic assay was used to determine the sex of 106 out of 125 samples. The remaining samples either failed the assay or did not have sufficient DNA.

## RESULTS

### Photographic Mark-Recapture

Model selection was accomplished using Bayesian posterior predictive error from candidate models (Gelfand and Ghosh 1998) which supported the use of an open population model which accounts for mortalities, temporary emigration, and re-immigration; compared to the standard Cormack Jolly Seber model (no turnover) or a model that only allowed emigration. Goodness of fit of the model was assessed using a posterior predictive test (Durban and Elston 2005). Annual capture probabilities were similar between areas (0.21 and 0.23, respectively). The re-immigration model estimated an average annual abundance of 54 whales at AUTECH (95% Highest Probability Density Interval (HPDI) = 43-93) and 84 whales at SW Abaco (95% HPDI = 68-126). Comparing the full posterior distributions of the abundance estimates resulted in a probability ( $p$ ) of 0.94 that average annual abundance at the control site was higher than on the Navy range. Estimated parent population size was also higher at the control site; 82 whales at AUTECH (75% HPDI = 66-110) and 110 whales at SW Abaco (75% HPDI = 95-133),  $p = 0.73$ . Differences in turnover or rates of movement of whales in and out of the two areas may also be evident. The rate of emigration was slightly higher at AUTECH (0.17, 75% HPDI = 0.08-0.26) than at SW Abaco (0.11, 75% HPDI = 0.05-0.20) while re-immigration rates were lower at AUTECH (0.44, 75% HPDI = 0.20-0.70) than at SW Abaco (0.55, 75% HPDI = 0.28-0.79). Despite the broad errors associated with the estimated rates of movement, there may be a lower probability of individuals re-immigrating into the AUTECH site after emigration. Our results suggest that average annual abundance was significantly lower at the Navy range than at the control site and the rate of turnover of new whales on the Navy range may be higher.

## IMPACT/APPLICATIONS

This project is providing key information on the baseline population ecology of beaked whales in the Great Bahama Canyon to understand and mitigate the effects of naval activities within this area. Photographic mark-recapture and chemical analyses (see FY09 and FY10 reports) have been completed, and the initial findings suggest low annual abundance and fine-scale population structuring of beaked whales. Here we have reported lower abundance and higher turnover at AUTECH than at the SW Abaco study area but further investigation is needed to understand whether this represent a biological difference (e.g. habitat differences) or is related to response to Navy activities at AUTECH. Tyack *et al.* (2011) report movements of beaked whales off range in response to multi-ship tactical sonar exercises at AUTECH which provides some support for the latter explanation for higher turnover at AUTECH.

Work has yet to be completed as part of this study which will help address the implications of our initial findings. Application of distance sampling methods to the ship-survey data will provide information on comparative density of beaked whales in different habitats within the Great Bahama Canyon. The population genetics will investigate gene flow, population structuring, relatedness and phylogeography to evaluate site fidelity and social structure; and will provide further information on

the extent and scale of population structuring of beaked whales in this area. Combined these data will be used to better understand habitat use and movement patterns; both will be related to the possible effects of exposure to Navy sonar on the AUTEK range.

## RELATED PROJECTS

### *Monitoring beaked whale movements during the Submarine Commanders Course using satellite telemetry*

This project is a collaborative project between the Bahamas Marine Mammal Research Organisation, Southwest Fisheries Science Center and the Naval Undersea Warfare Center (David Moretti). Satellite telemetry is being used to monitor the movements and diving behavior of beaked whales and other odontocete cetacean species on the US Navy's Atlantic Undersea Test and Evaluation Center (AUTEK) range before, during and after sonar exercises in which multiple ships are using their tactical sonars. Field work during this project is providing opportunity to collect biopsy samples and photo-identification data at AUTEK. This project has been supported by the US Department of Defense (OPNAV N45 Dr. Frank Stone).

### *Behavioral ecology of deep-diving odontocetes in the Bahamas*

This project is examining key aspects of the behavioral ecology of six Department of Defense priority species in The Bahamas. We will integrate data acquired through individual photo-identification, molecular genetics, fatty acid, persistent organic pollutant and stable isotope profiles, satellite telemetry and acoustic recordings to characterize the social structure, residency patterns, reproductive biology, diet, foraging ecology, and population structuring of key cetacean species. Field work during this project is providing opportunity to collect biopsy samples and photo-identification data from throughout the northern Bahamas. The project has been supported by the Strategic Environmental Research and Development Program (US Department of Defense, Department of Energy and the Environmental Protection Agency).

## REFERENCES

- Durban, J.W. and D.A. Elston. (2005) Mark–Recapture with occasion and individual effects: abundance estimation through Bayesian model selection in a fixed dimensional parameter space. *Journal of Agricultural, Biological, and Environmental Statistics* 10(3): 291-305.
- Evans, D.I. and G.R. England. (2001) Joint interim report Bahamas marine mammal stranding event of 15 – 16 March 2000. National Oceanographic and Atmospheric Administration. 59 pp. Available from:  
[http://www.nmfs.noaa.gov/prot\\_res/PR2/Health\\_and\\_Stranding\\_Response\\_Program/Interim\\_Bahamas\\_Report.pdf](http://www.nmfs.noaa.gov/prot_res/PR2/Health_and_Stranding_Response_Program/Interim_Bahamas_Report.pdf)
- Frantzis, A. (1998) Does acoustic testing strand whales? *Nature* 392:29.
- Gelfand, A.E., and S.K. Ghosh. (1998) Model choice: A minimum posterior predictive loss approach. *Biometrika* 85: 1-11.
- Matkin, C.O., Durban, J.W., Saulitis, E.L., Andrews, R.D. Straley, J. M., Matkin, D.R. and G.M. Ellis (in press) Contrasting abundance and residency patterns of two sympatric populations of transient killer whales in the northern Gulf of Alaska. *Fisheries Bulletin*.



Simmonds, M.P. and L.F. Lopez-Juraco. (1991) Whales and the military. *Nature* 351:448.

Tyack, P.L., Zimmer, W.M.X., Moretti, D., Southall, B.L., Claridge, D.E., et al. (2011) Beaked Whales Respond to Simulated and Actual Navy Sonar. PLoS ONE 6(3): e17009.  
doi:10.1371/journal.pone.0017009